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WORKING PAPER
on
THE MICROCOMPUTER:
TECHNOLOGICAL INNOVATION AND TRANSFER

by
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December 16, 1975

Prepared for
DEPARTMENT OF DEFENSE
DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
Contract No. MDA903-75-C-0131
ARPA Order No. 2857

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PREFACE

A research program to better understand technology transfer within the Soviet Union, whether that technology is obtained from outside or internal sources, is currently underway. Ultimately, this program should assist U.S. decisionmakers in analyzing a variety of related questions, including those associated with aspects of export embargo controls. This anticipated three-year program is just completing its first year.

As part of this effort it was considered worthwhile to gain selected insights from technology transfer activity by economic systems outside the Soviet Union. Within this context, a specific example of U.S. technology transfer was deemed a valuable exercise: the microprocessor/microcomputer innovation of recent vintage was chosen as a particularly appropriate vehicle. Although this innovation is just initiating its ascendancy, the first shapes of its technology transfer mechanisms are already formed and, most probably, subsequent transfer will follow along paths already roughly discerned.

As a prelude to the transfer aspects, the discussion covers factors describing the innovation itself. These factors not only help in better understanding the transfer mechanism but also provide important stand-alone value.

The literature abounds with microcomputer views but little providing basic insights. Therefore to augment the usual literature background search, personal interviews were held with key managers from all the major microprocessor/microcomputer manufacturers and selected other competing companies (see Appendix A). In so doing information was also obtained about other competitors (since interviewees had direct experience in many companies). These personal contacts provided an indispensable dimension to understanding this innovation and its transfer mechanisms.

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SUMMARY OBSERVATIONS

(1) The microcomputer/microprocessor innovation traces its lineage directly from the presence and stimulation of free-enterprise mechanisms that strongly encourage the creation of innovations, often of drastic proportions. These mechanisms derive from our basic economic system, the personal mobility allowed within that system (and pursued diligently by the electronics industry), and more fundamental influences within our society. In particular the venture-capital concept, in some ways the very essence of the capitalistic system, provides the means by which newly-formed and small organizations can enter a particular marketplace and application area which larger companies may have chosen to neglect. For the electronics industry especially this latter financing instrument has played a major role.

(2) As differentiated from its predecessors, the microprocessor--the heart of the microcomputer--did not evolve from conscious efforts by the U.S. Government, particularly the military agencies, to achieve such a capability. The military did not directly contribute as an R&D patron, initial purchaser of new components or, more generally, as a candidate target for component companies seeking a major military market. Quite to the contrary, the innovation itself was spurred by non-military interests, initially from electronic calculator manufacturers. This instance distinctly differs from the transistor and integrated circuit predecessors in which the military played a major role in the genesis and initial development for each.

(3) The microprocessor manufacturers have focused their initial marketing efforts mainly upon computer and computer-related activities. The key innovating manufacturers have sought high-volume, non-military users which they consider more accessible and less encumbered by constraints imposed, for instance, by the temperature and high-reliability demands typical of military applications. Conversely, smaller companies with more limited resources do consider the military as appropriate customers. These smaller companies generally choose a specific "pocket" in which they can aim for higher-priced, higher-performance components usually accompanied by the smaller production runs typical of military needs. In a general sense, the marketplace is polarized by the larger houses seeking off-the-shelf (OTS) products geared to high-volume non-military markets, while the smaller component companies look to the appropriate possibilities offered by the military.

(4) Technology transfer has been achieved via the manufacturing group that serves many customers, both military and non-military. Particularly for microprocessors, the manufacturer is highly dependent upon his customers since the software and application aspects are so critical. A close rapport generally exists between the manufacturer and his clientele which allows for a continuing upgrading of product performance for all customers. This is particularly relevant for military interests since, as noted above, first emphasis has been directed to non-military users.

(5) The second-source mechanism provides a major accelerating force to broaden the microprocessor application base. Via this technique other manufacturers may copy an accepted innovation, perhaps improve it, and capitalize on the innovator's ingenuity and pioneering effort. Users may then obtain the new component from two or more producers, thereby minimizing the user risks associated with purchasing from a monopoly manufacturer. For the microprocessor this mechanism has already helped to transfer and diffuse the technology to an ever-growing user group.

(6) In a similar mode, technology innovation and transfer have been greatly facilitated by the infrastructure supply group serving the components manufacturers. Over the years, a closeness has also developed between these two groups, thereby allowing the supply companies to serve as a focus of knowledge for all their users--in this case the components manufacturers. The latter lean heavily upon their suppliers for production know-how since, indeed, microprocessors are perhaps the most complex product manufactured by U.S. industry.

(7) The U.S. electronics industry supplies components and systems for a worldwide marketplace. Although various nationalistic inhibitions frustrate free flow over national boundaries, these factors generally exert minor influence overall. For the microprocessor, the role of foreign manufacturers, especially Japanese electronic calculator houses, was critical in providing the impetus for initial microprocessor development. Specifically, the innovation itself emerged from a close working relationship between the innovating U.S. company, Intel, and a Japanese customer seeking an improved calculator design.

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Foreign users of microprocessors, particularly those seeking an innovative edge relative to their U.S. competition, serve as a major stimulant to U.S. industry. In today's worldwide economy, any diminution in this relationship--however imposed--could reduce this impetus for innovation.

* * * * *

As an overview, the major U.S. technology-transfer mechanisms--both at the manufacturer and user levels--noted for the microprocessor/microcomputer innovation draw upon the following factors:

- Considerable personal mobility, driven by material and non-material aspirations
- Second sourcing, facilitating and multiplying an innovation's acceptance and credibility with a user group
- Manufacturers serving users from all sectors of the economy and the international marketplace
- Manufacturers' supply infrastructure similarly serving many users (here, the manufacturers themselves)
- Service groups providing various inputs for smaller users with limited resources
- Variations of the vertical-integration route, up or down
- Strong incentives to seek newness, based on the attributes of a free-enterprise system

These items suggest the rudiments for a comparative analysis of technology transfer in the electronics components industry here and elsewhere--as in the Soviet Union. Although this report specifically views one innovation, much pertains to other U.S. electronics innovations and, to hazard a guess, selected other high-technology innovations here.

WORKING PAPER
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THE MICROCOMPUTER: TECHNOLOGICAL INNOVATION AND TRANSFER

INTRODUCTION

For about 20 years the U.S. electronics industry, particularly its components segment, has been characterized by the dynamic activity resulting from a continuing flow of major new products, both at the components and systems levels; associated lowering prices, sometimes of dramatic proportions; the creation of new companies to introduce and exploit various related opportunities; the loss of dominant positions and sometimes even the exit of companies with previously established positions to newcomers offering favored innovations; a constant reshaping of the industry impelled by the new entrants and their innovations; and a general reinforcement of the electronics industry as a truly "mother" industry to other sectors of our economy.

Probably no other industry has received similar publicity relative to the creation, transfer, and diffusion of its new technology. A fundamental belief held by the most dynamic practitioners in the industry clearly contends that greater market penetration and multiplying applications depend upon lowering prices: consider the anti-inflationary benefits of reduced prices, usually accompanied by improved performance, exemplified by the long-term rise in available computer capability per user dollar spent or the more recent highly-publicized price declines incurred by hand-held calculators--to cite only two applied examples.

As its newest participant, the microcomputer may also exert not only great impact on the electronics industry but on the economy overall. Some believe, as does this author, that its influence will ultimately transcend any of its predecessors. Just on this basis alone it is deserving of study. But inevitably it will become a major and controversial pawn in East-West trade since the COMECON countries, particularly the Soviet Union, have been most anxious to obtain the latest and best U.S. technology. For microcomputers, U.S. industry now holds all the trump cards: there is no Number 2! Although

the issue has not yet surfaced, it is inevitable that the microprocessor/microcomputer technology will be the subject of much embargo-control controversy in future years. The Soviets will request both component and industrial capability and some U.S. firms will be willing to accommodate them, thereby raising a dilemma for U.S. governmental authorities.

This report aspires to offer an understanding of the innovation itself and the initial technology-transfer mechanisms experienced. Although some of both factors typify electronics innovation experienced over the past two decades, other aspects are unique to this particular innovation.

BACKGROUND

The microcomputer may be considered an extrapolation of the computer innovation conceived in the wartime years of the mid-forties but first commercially available in the mid-fifties. From a technical standpoint four computer generations have straddled this 20-year period:

- In the mid-fifties, Univac and IBM introduced the first computers utilizing vacuum tubes.
- The second generation, using transistors, gained market acceptance in the late fifties and early sixties as a rush of new entrants--both established and newly-created companies--entered the burgeoning computer marketplace.
- The third generation appeared in the mid- to late-sixties capitalizing on the integrated circuit (IC) innovation which, in hindsight, can now be dubbed SSI (small scale integration).
- With microcomputers, a creation of the early- to mid-seventies, LSI (large scale integration) components became commonplace.

Two distinct special considerations should be noted when one reflects on the chronology cited above. First, the IBM 360 line, initially announced in the Spring of 1964 and reaching production a few years later, used what many considered a 2-1/2 generation technology called the SLT (solid logic technology), a hybrid that was a cross between discrete and monolithic

technologies. Second, the first minicomputers--basically a price and size rather than capability designation--appeared in the mid- to late-sixties, presenting a distinct discontinuity in the computer direction that had dominated its first decade of acceptance. The innovator, Digital Equipment Corporation (DEC), brought out its first minicomputer in 1963 at \$27,000 and its real "winner", the PDP-8, in 1965 at \$18,000. The company's 50,000th installation was recently celebrated.

Today's microcomputer and the associated industry forming about it can be characterized in the following manner:

- Again, computer capability is offered to the user at a considerably lower price, about an order of magnitude less expensive.
- It capitalizes on a major new technological innovation available from the electronic components industry and, as in previous instances, the new component will facilitate new applications, which in turn will demand more and better similar components, which then will lead to even greater application breadth, etc., etc.--one feeding the other to the mutual betterment of both.
- New companies enter the marketplace as established companies, either those in the computer field already or outside firms, choose optimum strategies.
- As a generalization the major uses for microcomputers, at least at the outset, appear to be applications that heretofore did not employ computers in any mode.
- The traditional, established computer companies are now forced to ponder the role of a new innovation--as happened earlier with the minicomputer. The boundary between microcomputers, the high end of the calculator line, and the low end of the minicomputer family has become hazy. A data terminal, either remote or close to the parent computer, assumes new configurations as such terminals take on computer-like functions, e.g., data preprocessing and selected decisions.

- As with the transistor and IC innovations, the electronics components industry threatens to invade application areas, such as home appliances, heretofore resistant to its advances. A wide range of mechanical and electromechanical functions embracing many consumer, commercial/industrial, and government applications, now approach electronic feasibility as the cost/capability trade-off shifts--probably drastically. Microcomputing capability is available for a few hundred dollars now; consider that in 1964 the bottom of IBM's 360 line leased for \$9,000 per month stripped down.

Perhaps most important is the realization that the microcomputer offers a capability simply nonexistent before, namely, computing power need not reside in a formal "black box" called a computer--whether the large computer housed in an air-conditioned room or the small low-end minicomputer pushed on to the factory floor. Computing power, certainly in a limited mode, now approaches commodity status and, eventually in the long run, its cost moves toward a zero asymptote. The implications of this reality are awesome. And, few in the industry--makers or users--have contemplated the eventual potential impact of this innovation (which will probably transcend the vacuum tube, transistor, and integrated circuit). Perhaps Kahn and Weiner were remarkably prescient in their The Year 2000:

If the middle third of the twentieth century is known as the nuclear era, and if past times have been known as the age of steam, iron, power, or the automobile, then the next thirty-three years may well be known as the age of electronics, computers, automation, cybernation, data-processing, or some related idea.

TECHNOLOGY CREATION

Although technical detail may detract from this narrative, one cannot discuss so complex a technical innovation without touching on at least some of its intricacies. Appendix B addresses this need, allowing the reader to gain a better insight into the technical aspects--if he so chooses.

Ultimately this report mainly considers technology transfer, the means by which a technology is transferred to a user base. Admittedly differentiation between transfer and diffusion, utilization, and application is ambiguous. Generally, the following questions are of interest:

- How does a new technology eventually become embodied in user applications?
- How fast is this transition effected?
- Does the innovation benefit a broad spectrum of users, or is it relegated to specific pockets?
- Which characteristics of the producing industry, the users, or the overall environment as shaped by government and other institutions appear to accelerate or impede this transition?

To respond to these questions (among others) it is indispensable that any viewer must first be familiar with the genesis and initial development of the microprocessor and its successors. This component will be emphasized, rather than the microcomputer in toto, since it is the heart of the system--the pivot upon which the revolutionary breakthrough was achieved.

The Background for Innovation

In hindsight at least, four major trends created the backdrop which contributed to the microprocessor innovation.

MOS Technology Growth. The MOS technology was originally developed in the mid-sixties but major technical and cost problems dogged its advance. Component companies touting products using this technology and user companies integrating such components into their systems were forced to back away and retrench--and the technology was off to a poor start, particularly relative to the bipolar versions that were definitely on the upswing with a solid base and future. The large electronic components companies were preoccupied with their bipolar opportunities.

By 1970, however, major technological improvements had been achieved allowing MOS componentry to effectively compete in selected pockets, namely applications in which high density and low cost were at a premium. At this point, MOS began to realize some of its potential, although still far back relative to bipolar. Fundamental problems had been resolved but much work was yet to be done if the MOS technology were to compete across a broad front of applications, rather than restrict itself to limited sectors.

Electronic Calculators. The United States, once pre-eminent in the calculator market, had lost this premier position as the Japanese more aggressively used transistors in a family of calculator products. The pendulum swung back in favor of U.S. calculator companies when the MOS technology came into its own via the efforts of U.S. electronics firms. In 1971 the first hand-held electronic calculator was offered, selling at about \$240; since this introduction, the calculator field has experienced exponential growth through 1974 with many hand-held versions providing the cutting edge. Essentially, all such calculators, whether made by U.S. or non-U.S. manufacturers, utilized components manufactured by U.S. companies. Several of the major component houses also decided to go the upward vertical integration route, not only selling such components to others but also using them in calculators bearing their own label; such companies include Texas Instruments, Rockwell International, National Semiconductor, and Mostek, among others.

This application area provided the first major consumption for MOS products, thereby supplying a firm base for MOS companies to proceed forward and continually improve the technology.

Computer Industry Growth. Over the past decade, major attention has shifted to the means by which the computer mainframe is assessed, with less relative attention paid to the mainframe itself. This shift is a natural outgrowth of computer advances achieved through, about, 1970. With this change in emphasis, the need for reliable, versatile, and relatively low-cost terminals took on higher priority, thereby impelling the development of a technology that could satisfy this requirement. Generally, the computer field was still viewed as a major growth industry, with the greatest opportunities

lying in non-mainframe areas. Therefore, the impetus to provide such a needed technology to a growing industry was apparent. The question resolved itself to identifying the appropriate technology with sufficient performance versatility at reasonable prices. But there was no doubt that if a candidate could provide such attributes, the market was assured.

Computer Limitations. With the years, the computer and its related systems had achieved major versatility and broad market penetration. Still, there were wide-ranging families of applications in which a computer-type function was required without the formal computer. For applications relating to automobiles, home appliances, entertainment, industrial control, segments of military electronics, and telecommunications--to name only a few--the opportunities for computer functions were unbounded provided that function could be obtained at the right price, with the appropriate performance characteristics, and, especially, not constrained by the physical limitations of a formal "black box" designated as a computer, even with the smaller versions introduced in the past few years. If a technology could come forth satisfying the constraints noted above, then a totally different computer market base might be realized. This base would be measured in terms of unit sales of automobiles, home appliances, data terminals, with possibly several and even many microcomputers per each overall system. Total computer sales may project then to tens and perhaps hundreds of millions of microcomputer units, compared to today's estimated 200,000 worldwide computer installations. The potential could be staggering.

* * * * *

With these background factors, the microprocessor/microcomputer innovation came forth. Its evolution and the sub-industry created to capitalize on its initial success offers a revealing insight into the technological innovation process and the change patterns induced on the industry and its users when the innovation is viewed as a "winner" of large proportions. In some aspects, this innovation tracks others in the industry, but in a few respects it represents a major departure possibly portending significant consequences.

The Innovation

By most accounts, the microcomputer/microprocessor innovation is attributed to Intel Corporation, a Santa Clara, California company formed in 1968 by two key managers from Fairchild Semiconductor. At the outset, they single-mindedly pursued major new innovations utilizing the MOS technology for semiconductor memories--a practically non-existent market then. One of its customers, the Japanese calculator company Busicom, asked Intel to supply it with sophisticated, custom integrated circuits for the new Busicom electronic calculator family. The challenge of this customer demand led an Intel engineer to view the calculator's electronic functions in a different manner. Except for the most expensive versions, calculator electronics is "hard-wired" wherein the components are permanently interconnected on a printed-circuit board and directions are provided by the calculator user. A new concept was developed whereby the hard-wire approach shifted to a software technique more typical of problem-solving on general-purpose data-processing mainframes. Using this new technique a microprocessor and two memory devices provided the entire basic electronics componentry. With this innovation, the calculator is now a simple general-purpose computer offering more power and flexibility to the calculator (and, ultimately, opening up the plethora of applications alluded to earlier). Apparently Intel management strongly sensed the potential of this new route, particularly in non-calculator applications, and pursued the idea assiduously. The microprocessors were applied in the original calculator function, in line with the Busicom application, thereby allowing Intel to test out its feasibility. Soon after Intel offered its first microprocessor, the 4004, originally priced in small volumes from \$300-\$400 per unit. This device was adequate for decimal arithmetic; its successors, the 8008 and 8080, provide much more potency for scientific and word-oriented applications. Each has led the field driving Intel into a dominant market position based on monopoly status.

With this innovation a marvelously simple approach, achieved through major advances in the MOS technology, signals a significant breakthrough in the means by which computer logic functions can be obtained. Microprocessors could be mass-produced--with all the economies implied--and

the particular needs of any given application provided by customized memory chips. This radical departure from a traditional historical pattern was duly noted by creative logic and system designers. Initial Intel successes with this group aroused much attention, thereby attracting those who could and would compete with Intel for a burgeoning market. Momentum was building up.

Imitative Competition

As the electronics industry has experienced for twenty years, the appearance of an innovation achieving or about to achieve major market acceptance triggers a flurry of activity by competitive manufacturers seeking to capitalize on a potentially major opportunity. So, too, with the micro-processor. Several ingredients contribute to this imitative competition.

Company Participation. Imitative activity, implemented in many ways, allows new competitors market entry by riding an innovator's coat tails. A variety of companies have already entered the microprocessor field:

- Established electronic companies with recognized competence in the components field (e.g., Texas Instruments, Motorola, Fairchild, General Instruments, RCA, National Semiconductor, Signetics)
- Smaller and newer components companies (e.g., American Micro Devices, American Micro-systems, Monolithic Memories, Western Digital, Mostek)
- Traditional systems houses (e.g., Rockwell International).

The spectrum is wide and varied populated by companies with annual sales above \$1 billion to smaller ones in the \$20 million-dollar range, those established during the past few years to others with components history tracing back decades, some with a broad range of products and others with a very narrow-based product line, those only in the components field to a few in components and systems, and many only participating in electronics to others in electronics and unrelated fields. As differentiated from many other

traditional industries, the mix of manufacturers changes relative to its predecessors. For instance, most of the major integrated circuit manufacturers of ten years ago are now in the microprocessor field, but none enjoys a leadership position; what the future holds is anybody's guess. The very nature of the industry, for reasons partially discussed subsequently, encourages a dynamic restructuring which is all but impossible with many industries, such as automobiles. Leadership has not and is not forthcoming from other companies that normally might be considered the strongest contenders based on technical capability, market penetration, and management expertise. For the microprocessor, as for its transistor and IC predecessors, the industry has been reshaped bringing new champions to the fore and pushing former leaders into subordinate positions. Inevitably, key people play key roles.

Personal Mobility. Voluntary personal movement has always typified the electronics components industry, particularly in the last 20 years. The opportunities have attracted a breed of managers with few inhibitions to move as new opportunities are perceived, mainly based on pecuniary gain. This phenomenon has already characterized the microprocessor sector:

- The new MPU marketing manager at Mostek recently left his position at Motorola as systems engineering manager for MOS products.*
- The new microprocessor marketing manager at Fairchild recently moved from Signetics**.
- At one major manufacturer, the present manager of the microprocessor/microcomputer program held an identical position two years ago with another competing components house.
- For newer, recently-established companies, all their staff are recently moved.

This small sprinkling only superficially indicates the magnitude and significance of inter-company movement in this field. In personal interviews

* "Mostek Appoints MPU Mktg. Chief", Electronic News, October 13, 1975.

** "FC&I Realigns MPU Marketing", Electronic News, September 29, 1975.

with managers from several of the major microprocessor companies, it was apparent that this mobility was, indeed, a key factor in establishing their competitive positions. Some of the movement was directly traceable to their desire for microprocessor competence while other such changes predated their microprocessor entry, i.e., the mobility was motivated by non-microprocessor factors, but undoubtedly new staff added to the company's strength in the microprocessor field when this area was eventually pursued.

The whole area of inter-company mobility is a separate subject worthy of much more lengthy discussion. It is facilitated by a capitalistic economy, with the electronics components industry probably the most diligent practitioner of this characteristically American phenomenon. One key contributing factor is worthy of special note.

Venture Capital. Directly related to the comments noted above is the presence of a venture-capital mechanism that has exerted great influence in the electronics industry over the past two decades. This mechanism has fueled the creation and growth of new companies willing and able to pursue new paths that larger and more established companies often neglect. Essentially it offers an investor the chance to put his money into a newly-formed company in the hope that the fledgling will eventually succeed--and succeed big. The sources of the capital are many and varied: formal venture capital houses, private investors, banks, larger and more established companies, investment funds of many kinds, and numerous others willing to run the risk of total loss of their investment weighed against the large success potential. The venture-capital participants normally enter the scene at one of two points, either at the initial formation when the key participants are setting up the company, or later when larger funding is needed as the company's opportunities become capital limited and outside financial sources are required. In return for the investment, an equity position is obtained and sometimes limited management control.

The original key operating personnel always share in the equity stake, with the burden of responsibility for actually making a success of the operation. Besides the obvious potential of a large financial return--which can sometimes be extremely large--the non-pecuniary motivations also

appear to be substantial. In interviews with such persons in key management positions and from various readings in the field, it is apparent that these non-material incentives are real and powerful. The frustrations of larger organizations, the adventure in forming a new company and usually traveling a new path that the larger companies are unwilling to tread, the flexibility of running one's own business, and the ego-enhancement of creating and riding a winner are all persuasive--particularly for those where the monetary aspects are not of overriding interest. The venture-capital outlet encourages innovators--and imitators.

Second Sourcing. With second sourcing a user is guaranteed at least two suppliers for a component that he will use in great volume and/or over a long time period. This imitative activity has been spurred by the military's requirement for an insured supply for its long production runs; typically components even with extremely attractive characteristics will not be designed into systems unless at least one second source is available. More recently, the large computer companies, often committed to long production runs also, have begun to place similar constraints upon their vendors. In general, this trend indicates an unwillingness on the part of large users to place themselves wholly at the mercy of a single supplier--even a reputable and established company--for fear the vendor, for whatever reason, cannot or chooses not to supply the needed components at some future time.

Besides the impetus from the user side, the competitive nature of the industry often forces companies into a "bandwagon" response. When a major new component begins to enjoy substantial market penetration, or when it becomes apparent that a component will achieve wide acceptance, competitors often seek some means to capitalize on the success. The second-source route is available, either with or without the permission of the innovator. The imitator never offers the exact same product: he will claim some performance enhancement or lower price, and sometimes both. One such company unabashedly copied the industry's de facto standard and maintained that its replacement "... will plug into existing sockets and work exactly as if Brand I was still there," only better.

The advantages to the user of the second-source mechanism have been noted. Distinct advantages/disadvantages are encountered by the innovator and the imitator:

Imitator Advantages

- Capitalizes on innovator's mistakes (if any)
- Capitalizes on innovator's creativeness and initial cultivation of a market
- Allows him to reach the marketplace faster.

Imitator Disadvantages

- Enters the market late
- Must ride the innovator's coat tails
- Must achieve credibility on his own
- Must offer something better to entice users from buying the innovator's component.

Innovator Advantages

- May allow for an enlargement of the market which would not have occurred without second sourcing
- Indirectly reinforces his pre-eminence, since others have deemed it necessary or desirable to copy his products
- Where a license agreement has been agreed upon, income is received.

Innovator Disadvantages

- May reduce his market penetration, both absolute and relative
- May force him to lower prices.

There are numerous variations of the second-source mechanism including aspects of exclusivity, mutuality of exchange, and nature and motivation of imitator. It has already become a significant factor in the microprocessor/microcomputer industry:

- Rockwell International and National Semiconductor signed a long-term pact for each to manufacture and market the other's entire lines of microprocessors and associated hardware and software, for existing product lines and any that may be developed in the future.
- Advanced Micro Devices (AMD) has licensed both Raytheon and Motorola to second-source one of its bipolar microprocessors.
- Harris Semiconductor will serve as alternate source for an Intersil microprocessor.
- Rockwell International and AEG Telefunken agreed to a broad-ranging exchange of product and technical information for microprocessors and related products manufactured by each; this move allows Rockwell greater entry into the European market.
- National Semiconductor and Plessey, a major British electronics company, signed an agreement allowing Plessey to manufacture and market National's microprocessor products in the United Kingdom, while Plessey supplies technical systems and software support to current and future users of National's microprocessors.
- NCR will be its own second source for Intel components.

Other second-source agreements pertain, but this sampling clearly indicates that the industry seeks this mechanism as a major tactic, with some smaller companies basing their strategic thrust upon such moves. Besides the numerous formal second-source agreements, other situations exist, such as the Texas Instruments and Advanced Micro Devices' decision to second source some of Intel's products without Intel formal approval (it is not clear whether either of the two imitators attempted to enter into a formal agreement and Intel chose not to.)

Second sourcing is not new to the industry, as the microprocessor variation is typical of a recurring theme. Based on past experience and even the limited microprocessor history, the following benefits generally fall out from this phenomenon:

- First and foremost, the number of manufacturers increases, often with snowballing effect, definitely indicating to users that the producer base is building up, with the implication that the innovation is here to stay, and probably prosper.
- Particularly in the electronics industry, an outgrowth of more producers inevitably results in lower unit prices and improved performance.
- Both factors suggest a broadening of the user base as more producers seek buyers for their products, and potential users are enticed by the growing manufacturing base, lower prices, better available products--and undoubtedly by the efforts of all vendors, particularly the newer entrants.
- The effect inbreeds, as more applications require more components, allowing producers to lower costs (and normally prices) by moving down the learning curve, and possibly even attracting more producers into the competition. In short, all the previous trends are reinforced. The duration of this monotonic advance varies greatly, e.g., for hand-held electronic calculators, the sequence described above progressed for about 3-1/2 years before production exceeded demand and a resulting producer fallout and associated losses took place.
For other components, and particularly for certain systems, the timing has been much longer, but usually the greatest flurry of activity occurs when full success appears imminent but is not yet realized.

All the comments noted above suggest that the second-sourcing mechanism serves as a powerful incentive for producers and users to pursue a new innovation with zest. Implicitly, its absence may slow down the entire sequence noted and perhaps incur other negative changes of kind rather than degree. Above all, it

should be recognized that the trigger for the second-source interest is the recognition of a winning component, first by selected users and then, of course, by other producers.

TECHNOLOGICAL TRANSFER

As the microprocessor innovation began to establish its initial beachheads, the technology moved to users in a variety of ways. As with any innovation, selected user(s) must be willing to entertain some risk by integrating the untried innovation into a system or subsystem. For the microprocessor, it has been difficult to specifically categorize the details of this group, but certainly segments of the electronic calculator and computer and computer-related industries were in the vanguard. In hindsight at least this direction is quite understandable, since Intel, the key innovator, had strong ties with such customers; this is also true for the other two major competitors. These applications are all directed to consumer and consumer/industrial users. Of the three major competitors, only one has strong and established ties to the military while the other two have placed primary emphasis on pursuing non-military markets. The military and any other government agencies have had little or no direct influence on the microprocessor innovation. Indirectly over the years the military have supported the MOS technology, both via R&D activities and purchase of components or systems, in its technological growth and advance during the late sixties. However, the microprocessor innovation per se cannot be attributed to military support or influence, either by funding R&D activities leading to the innovation, purchase of initial high-priced versions, or the ambitions of the first producing companies to seek the military as an initial customer and subsequently to pursue non-military clientele. The complete absence of the military from the innovation scene represents a major turnaround from similar occurrences in the late fifties and early sixties when component companies looked to the military, either directly or indirectly, as the first users of their new products. Often the military also provided R&D funds. For instance, for the integrated circuit innovation of 10-15 years ago, the three innovating companies all looked to the military and eventually the space agency for the initial purchases via industrial contractors. No such background pertains to the microcomputer/microprocessor innovation.

This change in the military's role has probably contributed to the manufacturers' initial lack of interest in cultivating military markets. The manager of GTE Sylvania Electronics Systems group, noted that the commercial microprocessor vendors "Want to sell microprocessors by the thousands and don't want to make designs for custom military devices with a limited production potential"*. Similarly, a TI spokesman referring to its microprocessor plans noted that "It is TI's plan to take every opportunity to use standard hardware in new military system designs"*. This distinct shift of the military's market role, confirmed by interviews with various manufacturers, indicates that the military may no longer enjoy the initial attentions of the manufacturers--a major reversal from the past. How widespread and consequential this change will be is unknown.

For all users, military or otherwise, several specific mechanisms have been identified by which the technology has been transferred and diffused to a user base.

The Manufacturing Group

The manufacturers themselves have served as a powerful stimulus to transfer technology, since they typically deal with a broad spectrum of users. Two of the three strongest microprocessor companies have particularly close ties to many segments of consumer and commercial/industrial industries, while the third appears to be more narrowly based in its customer range but with strong ties to the military. The first two noted are essentially component houses while the third is definitely systems-oriented. Although each company has a distinct affinity for certain kinds of customers, based upon corporate policy laid down by top management, all will pursue markets, particularly large markets, as the opportunities arise: none has a preconceived notion to serve only one market to the exclusion of others, although each has preconceived ideas as to where its own best opportunities may lie.

Each company essentially sells a component or components to customers who integrate them into a system, for their own use, or for ultimate sale to others. For each, the following sequence applies:

* Robertson, Jack, "Microprocessors: The Hottest Parts in Military Markets", Electronic News, September 1, 1975.

- A close dialogue exists between the manufacturer and his customers. The manufacturer is particularly attuned to his customers' needs, while most customers are willing to be candid with the manufacturer in the hope the latter will address his (the customer's) needs.
- Based on this dialogue the manufacturer will design a basic component for a wide range of customers with similar needs, or a custom device specifically geared to a designated customer. In the former case, the manufacturer shoulders the total R&D cost, while a custom design may be cost-shared by both parties. Typically even the custom device becomes available to others (eventually).
- The component(s) is offered to a customer(s) who experiments with it in his own design. This stage is characterized by frequent feedback between both parties in an attempt to achieve satisfaction of the customer's needs. Particularly in the microprocessor field, the manufacturer must depend greatly--if not entirely--upon the customer's familiarity with the application, the design in which the microprocessor will be imbedded.

Such feedback is invaluable to the manufacturer in helping him better understand the advantages--and liabilities--of his component, thereby allowing him to improve his product accordingly. For most manufacturers many such dialogues and interchanges take place offering him a spectrum of feedback. Implicitly, such inputs facilitate or force him to make necessary changes, hopefully improving his products, which then benefits all future customers. In a technology-transfer context this rapport provides an indispensable input for product improvement with better and wider end-user coverage. Where a components house is committed to off-the-shelf (OTS) products, rather than custom design for limited customers, this knowledge and capability diffuses to many, rather than only the few. Where such manufacturers serve

both military and non-military customers, the benefits easily cross such boundaries, e.g., many instances can be cited in which each sector has benefited from initiatives taken by the other.

- Theoretically, this progression can continue indefinitely although, in reality, it ultimately reaches a point of diminishing returns as new innovations enter the picture. For the transistor, this sequence is deep into its maturity phase, while for the integrated circuit it is in some earlier intermediary phase of maturity; for the microprocessor, it is just beginning, particularly since relatively little conscious effort has been devoted to cultivate most military and many non-military applications relative to the considerable marketing resources devoted to computer-related fields.

Few major electronic components companies, and none in the microprocessor field, serve only one market or one customer. The larger firms seek to identify and cultivate high-volume purchasers, but such customers can be forthcoming from any sector of the economy; smaller companies look for "pockets" where their more powerful competitors choose not to go. This diversity allows the various manufacturers to serve as a major technology-transfer mechanism to many customers. As noted, this is particularly true for microprocessor components since the major competitors now in the field have relatively little familiarity with microprocessor applications, and therefore must depend on their customers for feedback. Although, obviously, limitations exist as to how such feedback may be used by the manufacturer when proprietary interests are at stake, there is also little doubt that in the aggregate this feedback raises the manufacturer's competence, allowing him to better serve his customers, now and in the future.

The Infrastructure Supply Group

In a similar vein to the comments noted directly above, technical knowledge is transferred along a broad base via the companies supplying manufacturers who make microprocessor/microcomputer components. Such relationships are not unique to this industry, as manufacturing industries of

all kinds depend upon others for a wide variety of their input needs. Even the most vertically-integrated company anywhere ultimately must go outside for certain finished products, services, raw materials, and other inputs which it cannot or chooses not to supply on its own.

Over the years the supply industry serving electronics components companies has become increasingly large and sophisticated. This group consists of companies manufacturing equipment for preparing wafers, testing components in all stages of their production, assembling intermediate and final products, and monitoring the many scientific and engineering parameters. Although some of the larger components companies do maintain in-house support groups to customize equipment for their own particular needs, even they are highly dependent upon the supply companies for basic "bread-and-butter" products and for equipment which will ultimately be modified in a unique manner. For smaller companies, no such luxury exists: they must live with the products offered by their suppliers.

This supply group has developed an extensive and in-depth capability by working closely with its clientele, the components manufacturers. In large part its growth has been facilitated by the type of mobility discussed earlier, in which engineers and entrepreneurs perceive opportunities and venture forward, in this case supplying such needed equipment. This movement, often supported by venture-capital sources, has resulted in an extremely close working relationship between supplier and customer. Such rapport is particularly critical in the electronics components industry since the product rate of change is high implying a fast obsolescence rate for older equipment and a continuing influx of new and improved versions.

With the onset of the microprocessor component, this relationship has been forced to respond to some new pressures. Conversations with various components manufacturers suggest that the following factors apply:

- The supply industry is versatile and competent drawing upon some 20 years of serving the semiconductor electronics components industry. Its growth has been evolutionary and constant via the entry of new firms and modifications by older firms already serving the electronics industry in other capacities. Such overall

capability cannot evolve quickly since the competence is shaped by a supplier/user relationship that can only develop over many years. In the United States, the supply group is available to the components manufacturers who lean upon them heavily, thereby helping the manufacturers improve their processes and products and ultimately serving end users better.

- Although the microprocessor innovation has placed some new pressures upon the supplier group, basically these demands are of degree rather than kind. No new revolutionary equipments are called for. Improvements of speed and complexity have been sought but they represent a direct extrapolation of trends already on the scene for many years.
- The supplier manufacturers typically serve a broad spectrum of customers, who in turn serve the various sectors of the economy, i.e., both non-military and military interests. As a supplier company works with many customers, he in turn improves his products based upon such inputs, and such improvements are available to all. Therefore, he serves as a means of technology transfer and diffusion--as a common denominator to a broad range of customers. In this sense the analogy is complete to the manufacturing group mechanism noted above.

Service Groups

Interestingly, a large fraction of the first users of microprocessors/microcomputers were not large firms with ample resources, but smaller companies seeking to utilize the new innovation as the basis for a new product. Typically, such companies consist of a few key engineering and management persons, with limited resources at their disposal, little experience in the field, and a hope that a new product will bring success and fortune. These companies usually draw upon outside resources to assist them with specific tasks.

Over the years a computer-services industry has evolved providing users with software, computer power via time sharing and other more traditional batch operations, familiarity with specific operations where computers may be used, and other related services. Since the microcomputer places major emphasis upon software rather than hard-wired logic, these service groups have selectively assisted microprocessor users in their software applications. Formal means exist in which service groups can obtain software programs developed by the microprocessor manufacturers. These groups, particularly the larger companies, also carry their own staff who develop software, particularly for applications that may have widespread use. Whatever the mode these groups serve as a mechanism by which user companies, particularly small ones, can augment their capabilities, thereby facilitating or accelerating the introduction of new products and systems utilizing the new innovation--in this case, the microprocessor.

In a similar vein, design groups may assist users in the specific integration of the microprocessor into products. Such inputs are usually not forthcoming from companies within the above-mentioned computer services group. Typically independent, usually small, companies supply this capability.

To generalize, a support infrastructure is in place to facilitate the integration of the new innovation into products and systems. As noted earlier, the major microprocessor manufacturers are long on manufacturing capability and short on application know-how. For larger users this combination may not present any major difficulties. For medium and smaller users, however, and particularly for newly-established companies where many of the most dynamic new products surface, this support structure extends their limited capability, providing a sometimes indispensable input.

User Groups

Over the years the computer industry has developed formal organizations banding together users of a particular company's computers, often for a specific application such as banking. Users enjoy the option to contribute and draw from a pool of experience, including software programs, generated by other users. The user organization and, of course, the computer manufacturing company itself, serve as the focus for such transfer. Obviously

competitive considerations place some constraints but this mechanism has been a potent force in transferring technology, particularly the software aspects, to a wider user base.

The microcomputer companies, at least selectively, have initiated similar practices. In late 1974, Intel set up a users' library. The literature has noted other companies at least considering similar tools. It is reasonable to assume that they will pursue similar means to both better serve a growing user group and to become more knowledgeable themselves.

Vertical Integration

The electronics industry has experienced two major modes of vertical integration: first, the systems company integrating downward to specific components ultimately to be used in its own systems and, secondly, the components company seeking the value-added route and ultimately making end systems on its own using its own components. Variations of the vertical-integration approach include systems firms with part ownership in components companies and proprietary arrangements between these two parties, such as for special designs or second sourcing. In all such instances, the normal open-marketplace mechanism varies since there is some form of binding relationship between the vendor and the buyer. Our economic system allows for this variety, thereby satisfying a need for the various companies involved.

Some instances of this phenomenon follow:

- NCR serves as its own second source via an agreement with Intel, in which Intel supplies some but not all of NCR's microprocessor needs while NCR may supply the remainder. Of course, NCR does not compete in the open marketplace with Intel.
- Digital Equipment Corporation, in association with Western Digital, a west-coast components house, has designed a proprietary circuit to be used by DEC in its own microcomputers or MPU offerings. Now, Western Digital is offering these circuits to others.

- Texas Instruments has introduced a compatible line of microprocessors to minicomputers, perhaps unique to the industry. TI will offer any of these components or systems separately, clearly stressing that all parts are compatible as a user moves from the smallest component to the larger system.
- Data General, a major minicomputer manufacturer, already has an in-house semiconductor facility and could, if it so chooses, probably make its own microprocessors and related components.
- General Automation, another major minicomputer company, owns a 20% share in Synertek, a components firm.
- General Instruments offers components to outsiders but also considers its own systems divisions as customers.
- Hewlett-Packard maintains several separate IC facilities to service various divisions.

These variations of vertical integration have existed for some years within the industry. The picture is totally dynamic as products change and new companies enter the field. With microprocessors, the industry again confronts the make-or-buy decision it faced when the transistor and integrated circuit were introduced. Companies traditionally considered components houses, such as Fairchild, Intel, and National Semiconductor, have, to varying degrees, all gone the vertical-integration route upwards and now offer some end systems.

Manufacturer's Customer Support

The microprocessor innovation has forced a new way of thinking upon designers. As noted earlier, the stress upon hard-wired logic has been replaced by the greater flexibility of a concept breaking down the traditional barriers between the logic designer, the component designer, and the software engineer. The boundaries are vague with each folding into the other. Particularly for smaller users, the need to gain such all-around knowledge is critical. The components manufacturers have recognized this gap and have placed a major

emphasis upon generating operating software systems, which facilitate the application of their components into systems, and supplying the mechanisms whereby users can achieve this familiarity. These manufacturers offer courses and extensive field service to potential users. Apparently, large sums of money have addressed this particular need with outstanding results.

Besides offering the components several of the manufacturers (e.g., Intel, Motorola) sell kits of varying degrees of complexity to help potential users both evaluate microprocessors and related components and build microcomputers themselves. In a similar but related vein, distributors (e.g., Cramer, Schweber), who traditionally serve the industry as the middlemen to interface with small- and medium-sized users, also selectively offer similar kits to their clientele.

This approach attempts to compensate for the more limited resources of smaller users. Although they generally order many fewer components than their larger counterparts, their number is much greater. Without such assistance, they would be at a clear disadvantage, both absolute and relative to the larger companies. These intermediary mechanisms appear to be much greater in number and intensity than for previous components, suggesting that the manufacturers realize the radical departure the microprocessor innovation imposes and the subsequent need to somehow bridge the familiarity gap so created.

Foreign Influence

The U.S. electronics components industry dominates the world marketplace, yet in many specific application areas it competes with others, mainly Japanese and West European companies. In serving the calculator market, particularly the hand-held version, U.S. companies have totally dominated the scene, with no significant competition from others. Since the microprocessor clearly derives from its electronic calculator predecessor, this relationship between U.S. components suppliers and calculator manufacturers, particularly the Japanese, plays a significant role in the innovation's original conception and first transfers to real applications. All three of today's leading microprocessor manufacturers enjoy close ties with major Japanese calculator houses; the Intel relationship has already been noted.

This relationship, crossing national boundaries, offers manufacturers advantages that cannot be realized if they were only to serve a domestic marketplace. Certainly their potential market enlarges but, perhaps more importantly for the innovation conception itself, systems companies from other countries, such as Japan, have often been much more aggressive in creating outstanding new products. Japan's capture of the calculator market using transistors and initially sophisticated LSI components is a case in point. Generally the economic system in free-world countries facilitates such closeness, particularly through the U.S. subsidiaries in other countries. Such diversity clearly broadens the possibilities for innovation conception and eventual transfer, particularly in an industry noted for its innovative creativity; observations of the electronic scene in the United States, Japan, and Western Europe over the past 10 or 15 years clearly confirm this hypothesis.

Although numerous frustrating limitations introduce friction into this relationship, basically the ease of dialogue and market access are clearly evident. The various nationalistic instincts toward protectionism, as now being aired in the trade talks in Geneva, do not negate the fundamental ethic still encouraging accessibility rather than restriction. The U.S. components companies have increasingly become more world conscious of their marketplaces, and have taken steps accordingly. Their relationship with foreign users not only increases their market potential but forcefully contributes to the dynamism that has characterized the industry for so many years.

APPENDIX A

INTERVIEWS

APPENDIX A

INTERVIEWS

The following organizations were interviewed, all in person except for EDN:

Industry

American Micro Devices
Sunnyvale, CA

Fairchild Semiconductor
Mountain View, CA

Intel
Santa Clara, CA

Monolithic Memories
Sunnyvale, CA

National Semiconductor
Santa Clara, CA

Rockwell International
Anaheim, CA

Signetics
Sunnyvale, CA

Western Digital
Newport Beach, CA

Other

EDN (magazine)
New York, NY

APPENDIX B

BRIEF TECHNICAL BACKGROUND

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As an addition to the text's discussion, several basic definitions and terms are considered briefly:

Microcomputer. There is no single, commonly-accepted definition for the microcomputer. The boundary between several high-end electronic calculators, low-end minicomputers, and the microcomputer is vague, and all are moving targets suggesting that today's definitions may be invalid tomorrow. A microcomputer is a small minicomputer: it's lower priced, generally slower (rule of thumb is a factor of ten), always smaller, poorer on input/output capability, endowed with a less versatile instruction set, and generally characterized by less overall computer power. Basic functions are the same but, as with computers generally, the architecture may favor I/O needs or arithmetic operations or word manipulation, inevitably optimizing only one parameter compromises the others. Price is a poor yardstick since the overlap is great, but undoubtedly the lower end of the microcomputer line will always be less expensive than a minicomputer counterpart and, similarly, the low end of an electric calculator family will be less costly than any microcomputer. Today the smallest most rudimentary microcomputers can be bought for well under \$100, while the higher end edges over \$1,000.

Perhaps in its simplest and most revealing index, the microcomputer is a continuation of the increasing monotonic function, computer power/unit cost, experienced over the past 20 years: by any measures, this index has risen sharply.

Microprocessor. The microprocessor combines two of the four basic functions present in any computer: the arithmetic logic unit (ALU), that handles data, and the control unit that manages the computer's operations, a combination traditionally termed the central processing unit (CPU). This component, or components, is the heart of the microcomputer, providing the ingenious breakthrough. Optimally it can be mass produced using techniques and even similar production lines as other sophisticated semiconductor products. Its current price ranges well under \$25 per unit in large quantities, a remarkable achievement since it can replace dozens of discrete (SSI) IC components.

Microprocessing Unit. An interim step between the microcomputer and microprocessor is the microprocessing unit (MPU) which generally contains the microprocessor, selected memory, input/output devices, and several other components. It resembles a function that the industry has dubbed the "naked minicomputer".

It is emphasized again that these definitions are indicative rather than precise, an impossibility considering the dynamics of the field. Increasingly the more sophisticated microprocessor elements are one chip (rather than several chips which some companies have introduced) with selected memory on that single chip. Today many companies offer single-chip microprocessors but there is no single-chip microcomputer available; indeed, such a concept runs counter to the basic idea of the microcomputer.

The microcomputer capitalizes on another major semiconductor innovation, drawing from the same technology as the microprocessor, to achieve the computer function. In particular, semiconductor memories rather than their ferrite core predecessor provide memory capability. They are divided into three groups:

- Read-only memory (ROM) supplies permanent memory capability; the ROM is produced by the manufacturer and is not capable of change.
- Random-access memory (RAM) stores memory temporarily and may be continuously changed, as needed.
- Programmable read-only memory (P/ROM) is a hybrid of the ROM and RAM since it allows for changes in information storage use in a read-only mode. The customer or the manufacturer may effect this transition.

Transistor technology and most of the IC technology have been dominated by the bipolar concept in which conduction is achieved by the flow of both holes and electrons in the traditional p-n junction transistor. This technology, created in the Bell Telephone Laboratories, has provided the industry's fundamental thrust and enjoyed unchallenged dominance until about 1970.

For about ten years now, work has progressed on a related although differing concept for fabricating integrated circuits, namely the metal-oxide-semiconductor (MOS) approach, based on conduction of either holes or electrons,

but not both. This concept only became feasible in the past few years, thereby initiating a competition with its bipolar cousin in selected applications. Generally, MOS is less complicated and hence less costly and easier to make, capable of greater circuit density, and slower than its bipolar counterpart. In turn the MOS technology consists of three variations: the p type, the oldest and easiest to fabricate, based on a flow of "holes"; the n type, faster than the p variation but more difficult to make; and the complementary version which uses both types for lower power consumption and better noise immunity.

Both technologies can perform memory and microprocessor functions. To date the p/MOS technology has dominated both areas, but the n/MOS and bipolar varieties are now competing aggressively.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. REPORT'S CATALOG NUMBER
6		9
4. TITLE (and Subtitle) WORKING PAPER ON THE MICROCOMPUTER: TECHNOLOGICAL INNOVATION AND TRANSFER.		5. DATE OF REPORT & PERIOD COVERED Working Paper Sep 1975 - Nov 1975
7. AUTHOR(s) Herbert S. Kleiman		6. PERFORMING ORG. REPORT NUMBER
10		8. CONTRACT OR GRANT NUMBER(s) MDA903-75-C-0131 ARPA Order-2857
9. PERFORMING ORGANIZATION NAME AND ADDRESS Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia 22209		12. REPORT DATE 16 December 1975
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Defense Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia 22209		13. NUMBER OF PAGES 38
12		15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of this Report) Approved for Public Release - Distribution Unlimited		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Technological Innovation Technology Transfer Microcomputer Industry		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Thru interviews with U. S. major microcomputer manufacturers, first hand insight into technology transfer practices in this innovation was obtained and described. It was concluded that to a great extent, technology transfer in the microcomputer industry is typical of technological innovation in the U. S. electronics industry and that the U. S. Government soon will face serious questions concerning technology transfer issues stemming from the U. S. microcomputer industry.		